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WOX-5A ACCELEROMETER

(Artillery Projectile Copper-Ball Accelerometer)

21 MAY 1968

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UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND 20910

NOLTR 68-85

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WOX-5A ACCELEROMETER
(Artillery Projectile Copper-Ball Accelerometer)

Prepared by:

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Environment Simulation Division

ABSTRACT: A multipurpose accelerometer mechanically measures artillery projectile setback, spin, barrel-slap and target-impact accelerations. Twenty-three copper-ball accelerometers mount in the aft 2.75 inches of a Mk 73 VT Fuze or T-227 CVT Fuze body. Eight accelerometers measure setback at frequencies from 7200 to 20,200 Hz; eight similar accelerometers, opposite in direction, measure target impact; three pairs of accelerometers measure barrel slap (transverse acceleration) at frequencies of 5680 and 8380 Hz; one accelerometer measures spin (angular acceleration) at 1450 Hz or 1026 Hz.

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WOX-5A ACCELEROMETER
(Artillery Projectile Copper-Ball Accelerometer)

The WOX-5A Accelerometer was developed specifically for artillery projectile shock applications. The experimental accelerometer measures gun shock with acceptable accuracy under conditions so severe that measurements by other means are extremely difficult and costly. The work was sponsored by NWSO under ORDTASK SSO-001/212/R as part of a program of Basic Design Engineering on surface gun fuzes. The opinions and conclusions are those of the Environmental Evaluation Department.

The design contributions of Mr. J. W. Simkins of the Product Engineering Department are gratefully acknowledged.

E. F. SCHREITER
Captain, USN
Commander

V. M. Korty

V. M. KORTY
By direction

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REFERENCES

(a) BUORD LD 2275973, Parts List and Drawings for Mk 4 Mod 0 Accelerometer, 31 Mar 1948

(b) NOLTR 67-3, Artillery Projectile Shock, 4 Jan 1967

(c) NOLTR 67-151, Shock Spectra Measurements Using Multiple Mechanical Gages, 20 Sep 1967

INTRODUCTION

1. There are few recording devices that can survive the surface-gun environment and measure the many shocks experienced by artillery projectiles. Even in rare cases where measurements have been made with continuous recording instruments, the cost has been high and the returns have been small. There has long been a need for simple, self-recording gages to measure gun shocks and to identify anomalies in the operation of fuze systems. Development of the WOX-5A Accelerometer was undertaken to meet this need — the terms "gage" and "accelerometer" are used interchangeably in the report, as well as the terms "shock" and "acceleration".

2. The use of mechanical gages to measure surface-gun shock very likely began with the Mindlin Gage, a steel-ball, lead indenter device. The Mindlin Gage was later designated as the Mk 4 Mod 0 Accelerometer, reference (a). The gage, a nonlinear, low frequency system, was used only to determine the relative level of two shocks: setback and landing shock in vertical recovery gun firings. NOL began using mechanical gages to measure gun shock quantitatively early in 1965 in support of the Laboratory's gun-fuze development program. The first gages were conventional copper-ball accelerometers modified to fit a Mk 73 VT Fuze body. The measurements made were of setback and barrel slap during horizontal recovery firings in a 5"/54 gun. In a later version of the accelerometer four copper balls and masses were added to the Mindlin Gage to measure setback shock at four frequencies and the existing discriminator was modified and used to interrupt recording after setback. Both types of gages and gun-shock measurements made with the gages are described in reference (b), Section 3. The WOX-5A Accelerometer is an outgrowth of the multidirectional and Mindlin gages: it combines the functions of the two gages and measures spin acceleration as well. The operation and dynamic characteristics of copper-ball accelerometers are described in reference (c). Excerpts from the reference (c) instructions on the use of copper-ball accelerometers are included in Appendix B of this report.

WOX-5A ACCELEROMETER

APPLICATION

3. Artillery projectiles experience several shocks in service. The shocks measured with the WOX-5A Accelerometer are those produced during gun firings and when the projectile strikes a target or lands in a recovery area. As mentioned earlier, these are setback, spin (angular), barrel-slap (transverse), and impact accelerations; the WOX-5A contains separate accelerometers to measure each shock.

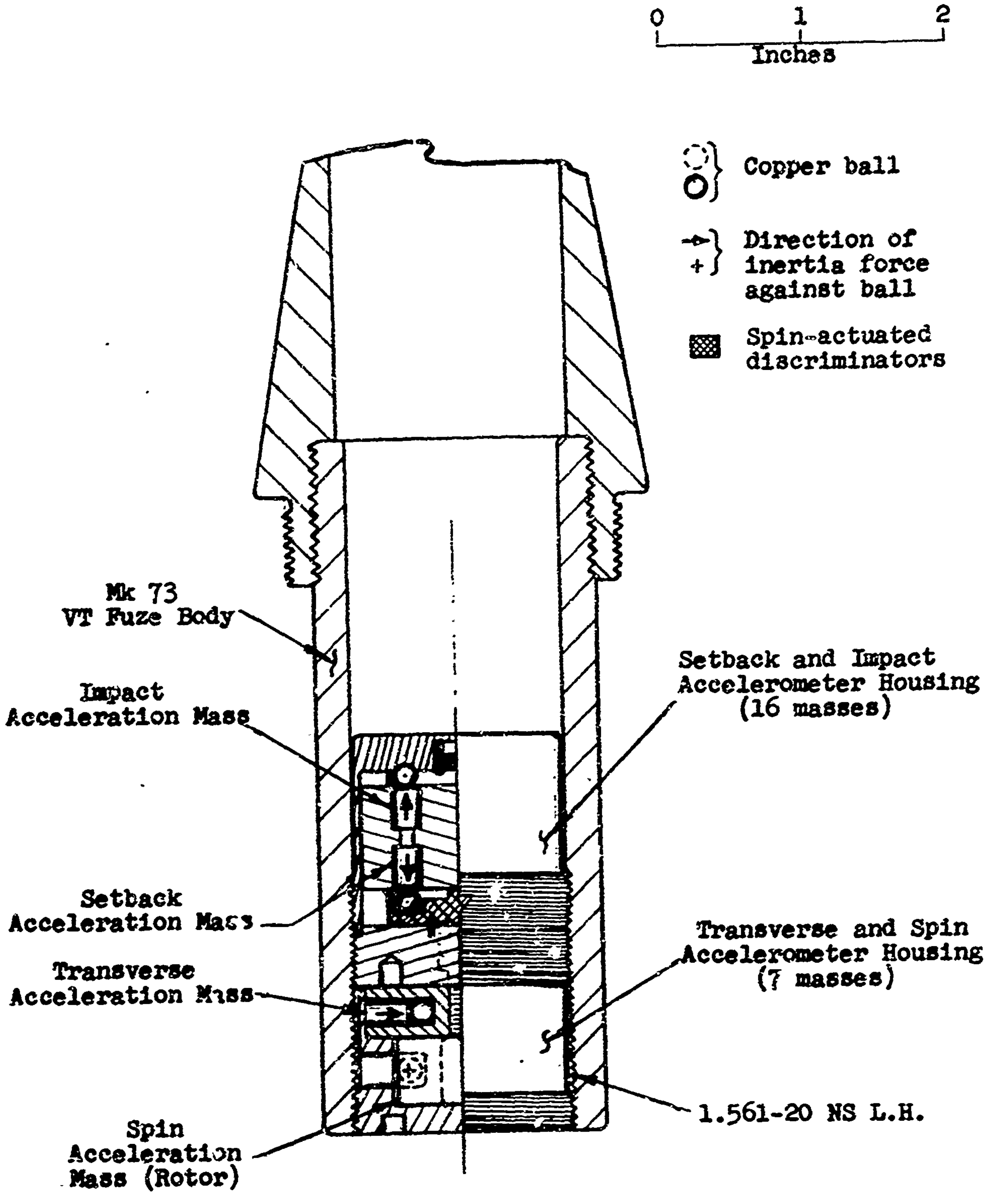


Fig. 1. WOX-5A Accelerometer

GENERAL DESCRIPTION

4. The WOX-5A Accelerometer, figure 1, consists of two separate housings that mount one behind the other in the aft portion of a Mk 73 VT Fuze body. The screw threads of both housings are 1.5ol-20 NS L.H. The overall length of the assembled units is 2.75 inches; their combined weight is 22 ounces. The large housing (13 ounces) contains eight setback accelerometers and eight impact accelerometers; both sets have spin-actuated discriminators. The small housing (9 ounces) contains three pairs of transverse accelerometers, equally spaced radially, and one spin accelerometer.

5. Each set of accelerometers operates independently. One set measures setback shock at eight frequencies from 7200 to 20,200 Hz. Operating in the opposite direction, a similar set measures target-impact shock. Three identical pairs of accelerometers, equally spaced radially, measure transverse shock at two frequencies: 5680 and 8380 Hz. One accelerometer measures spin acceleration at 1026 Hz when one copper ball is used, and at 1450 Hz when two copper balls are used. Assembly and parts details of each accelerometer are presented for reference in Appendix A. Calibration data for the accelerometer are presented in Table 1.

SETBACK ACCELEROMETER

6. The setback accelerometer occupies the bottom half of the large housing, as shown in figure 1. Eight inertia weights, eight copper balls and four anvil segments make up the unit. The weights range from 0.4 gram to 3.18 grams. The balls rest in form-fitting sockets in the four separate anvil segments; each segment holds two balls — the anvils are part of the spin-actuated discriminator mechanism.

7. The accelerometer discriminator mechanism consists of the four segments mentioned above, a grooved base to guide the segments, and four shear pins. In the ready position the pie-shaped segments form a closed circle as shown in figure 2A. Each segment is held inwardly by a soft wire pin and is keyed radially to guide it in its own quadrant. When spin reaches approximately 160 radians per second (well after peak shock has occurred), the inertia force of the segments shears the pins and the segments separate radially, sliding the balls from under their masses (inertia weights) as shown in figure 2B. This action interrupts recording.

IMPACT ACCELEROMETER

8. The impact accelerometer occupies the top half of the large housing and is identical to the setback accelerometer except that it is opposite in direction and is programmed to record after the projectile leaves the gun. The discriminator consists of wedge segments that separate the balls from the masses to prevent recording until setback shock is over. During setback a detent is inertially forced against the segments, locking them in place, as shown in figure 2C. When the setback inertia force drops off, the segments pull free from the detent under their own centrifugal force, freeing the masses to

Table 1

WOX-5A ACCELEROMETER CALIBRATION DATA

Discriminating
Eight-Mass Axial Accelerometers
(Setback and Impact Shock)

No.	Inertia Weight W (gm)	Frequency $f_n = \frac{1}{2\pi}\sqrt{\frac{k_1{}^{*}g}{W}}$ (Hz)	Calibration Factor (g/0".001)
1	3.18	7,200	5,300
2	2.26	8,500	7,380
3	1.50	10,400	11,100
4	1.05	12,000	14,700
5	0.83	14,000	20,000
6	0.67	15,700	23,000
7	0.50	18,100	33,400
8	0.40	20,200	41,700

Six-Mass Transverse Accelerometer+
(Barrel Slap Shock)

Inertia Weight W (gm)	Frequency $f_n = \frac{1}{2\pi}\sqrt{\frac{k_2{}^{*}g}{W}}$ (Hz)	Calibration Factor (g/0".001)
2.4	5680	3300
1.1	8380	7160

One-Mass Angular Accelerometer++
(Spin Acceleration)

Inertia Weight W (gm)	Frequency $f_n = \frac{1}{2\pi}\sqrt{\frac{kr^2}{I^{**}}}$ (Hz)	Calibration Factor (rad/sec^2/0".001)
82	Two Balls 1450	224,320
82	One Ball 1026	112,160

* k_1 = One-flat ball spring constant (37,000 lb/in.)

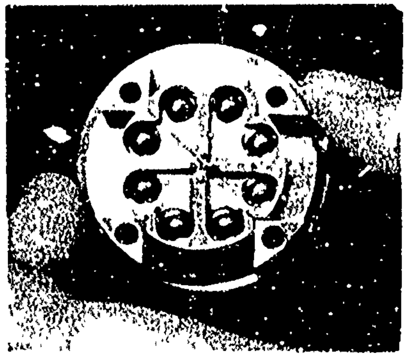
k_2 = Two-flat ball spring constant (17,500 lb/in.)

** I = Mass moment of inertia (in.-lb-sec^2)

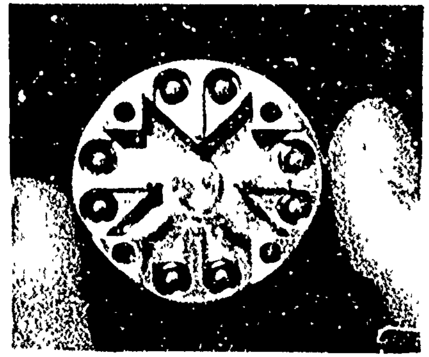
\+ Three pairs equally spaced radially

++ Accelerometer may be used with one or two balls. When two balls are used, deformation is taken as the average of both balls.

SETBACK ACCELEROMETER DISCRIMINATOR

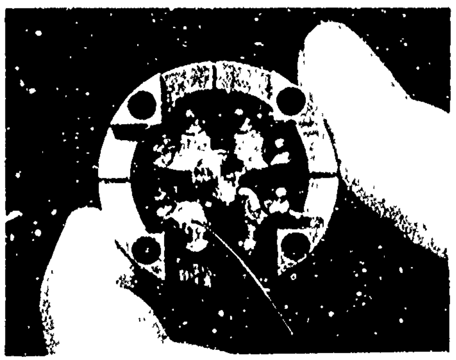


A. Segments and balls before spin reaches 160 rps. Masses (not shown) are fixed above balls.

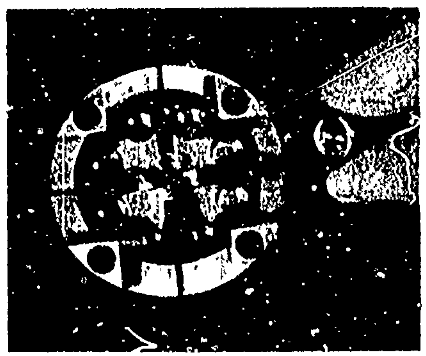


Segments and balls after spin reaches 1( ) rps. Balls are clear of masses.

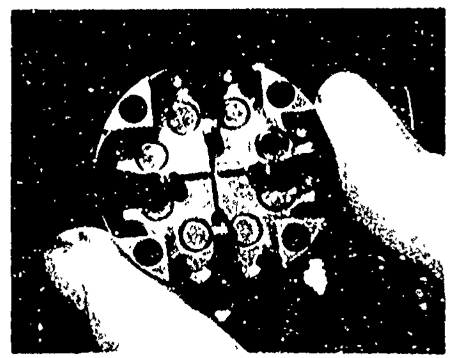
IMPACT ACCELEROMETER DISCRIMINATOR



C. Wedge segments and detent locked [illegible] ring setback shock.

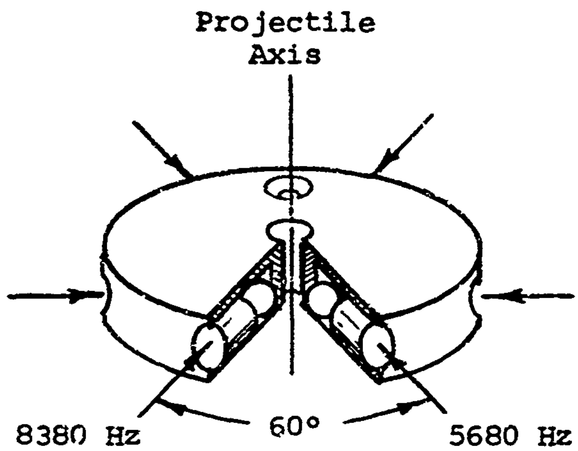


D. Detent shown removed. Segments are free to move.

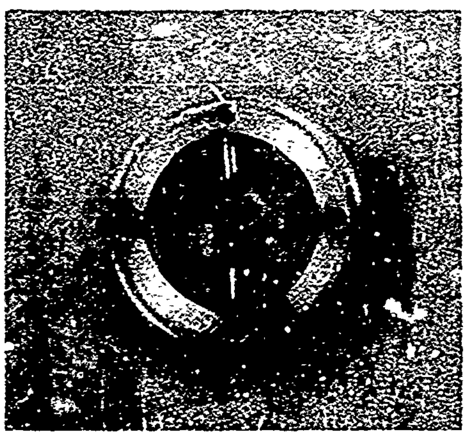


E. Segments separate and clear masses. Balls (not shown) are fixed under masses.

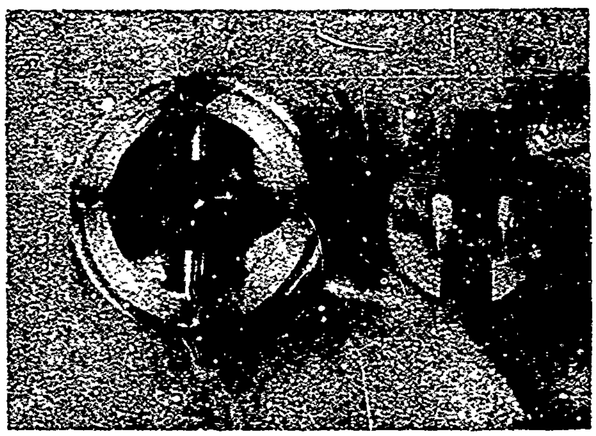
Fig. 2. Operation Sequence of WOX-5A Discriminators



A. Orientation of Transverse Accelerometers

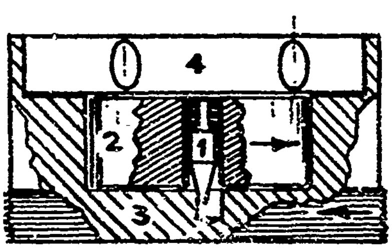


B. Rotor and Housing Assembly



C. Housing (left); Rotor and Detent Pins (right)

1 Detent Pin
2 Rotor
3 Housing
4 See A



Relative motion of rotor and housing

D. Complete Assembly

Fig. 3. Transverse and Spin Accelerometer

operate on the balls; the sequence is shown in figure 2D and 2E. The accelerometer measures target or recovery area impacts.

TRANSVERSE ACCELEROMETER

9. The transverse or barrel-slap accelerometers are located in the top portion of the small housing. The accelerometer masses are equally spaced radially and are assembled in pairs in each of three segments to record impacts at two frequencies, 5680 and 8380 Hz. The copper balls are located inboard to avoid preloading due to centrifugal force of the masses during projectile spin. Figure 3A shows how the accelerometer masses and balls are oriented. The accelerometer has no discriminator since barrel slap can occur several times during firing and there is no way to predict when the highest shock will occur. Despite this limitation, the accelerometer has proved useful in determining whether projectiles are receiving normal or excessive shock in the transverse direction. Figure 3D shows the accelerometer assembled in the spin accelerometer housing.

SPIN ACCELEROMETER

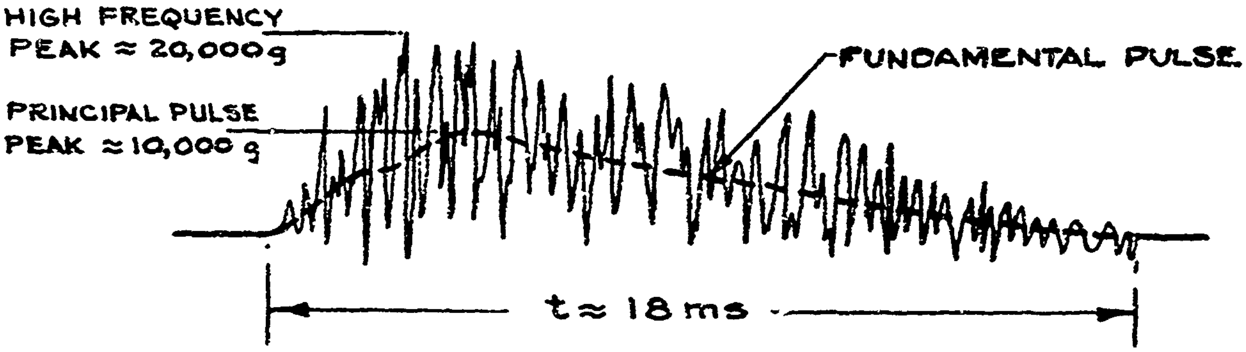
10. The spin accelerometer, located at the bottom of the small housing, consists of a close-fitting rotor free to turn about its axis only. Because of this constraint, the rotor is not affected by transverse shock. The assembled rotor and housing is shown in figure 3B. The copper balls are mounted in pins fixed to the outer housing as shown in figure 3C. When the housing is accelerated angularly (clockwise in all guns), an inertia force is exerted by the rotor against the balls and the balls deform just as they do in the linear accelerometers. One or two balls can be used with the accelerometer, depending on the level of angular acceleration. Normally, for accelerations up to 250,000 rad/sec^2 (new gun range), one ball is used in order to obtain a larger deformation. For higher angular accelerations (see paragraphs 12 and 15), two balls are preferred. Two spring-loaded, tapered pins wedge between the rotor and housing to take up any backlash which may occur in the rotor during acceleration; these are shown removed and resting on top of the rotor, figure 3C, and in the cut-away section, figure 3D.

11. Because this is the first application in which a copper-ball accelerometer has been used to measure angular acceleration, computations to determine the frequencies and calibration factors of the accelerometer are presented in Appendix C. As indicated previously, the operation and dynamic characteristics of the linear copper-ball accelerometers are described in reference (c).

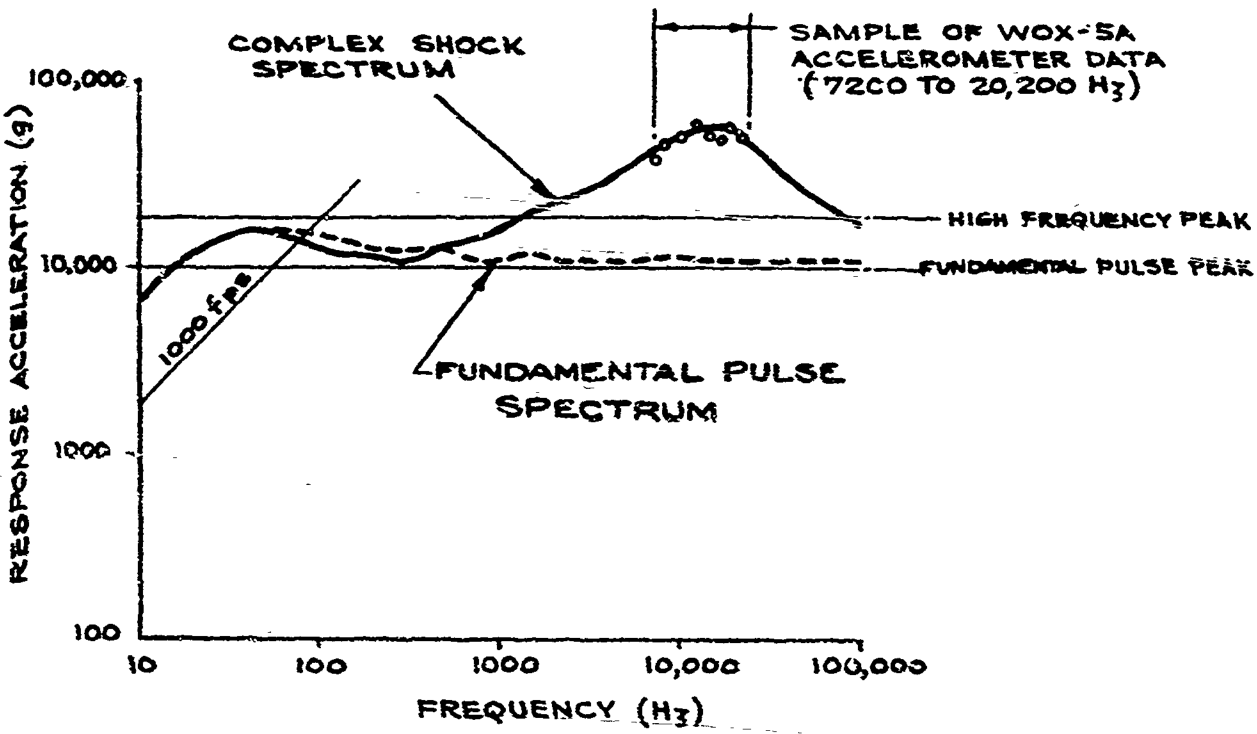
PERFORMANCE

COMPONENTS OF PROJECTILE SHOCK

12. Before discussing WOX-5A performance, some observations should be made about gun shock. Setback shock in guns, as measured in the projectile fuze, is complex. It consists of a single pulse (fundamental pulse, fig. 4A) that is proportional to the explosive charge pressure and of higher g, high frequency shocks that result



A. Hypothetical Setback Shock Signature
(Medium Severity)



B. Hypothetical Setback Shock Response Spectra

Fig. 4. Hypothetical 5"/54 Gun Setback Shock Data

from projectile and fuze resonances or from the effects of deteriorating barrel surfaces in worn guns. Projectile landing shocks are equally complex and in some cases more severe than gun shock. Barrel slap, an impact shock, is considered to be very high frequency and very short in duration. Even spin acceleration in some guns contains shocks in the high frequency region. These can result from torsional resonances in projectiles or from angular chatter because of rough rifling. The WOX-5A Accelerometers, being peak readers, respond to the higher g, higher frequency gun and landing shocks.

13. Projectile component hammering during firing can produce extremely high gage readings. These readings, generally in the 100,000g range, are quantitatively meaningless since they result from many severe impacts; however, they clearly indicate the existence of loose projectile components, or at the least, very high resonances in the projectile-fuze system.

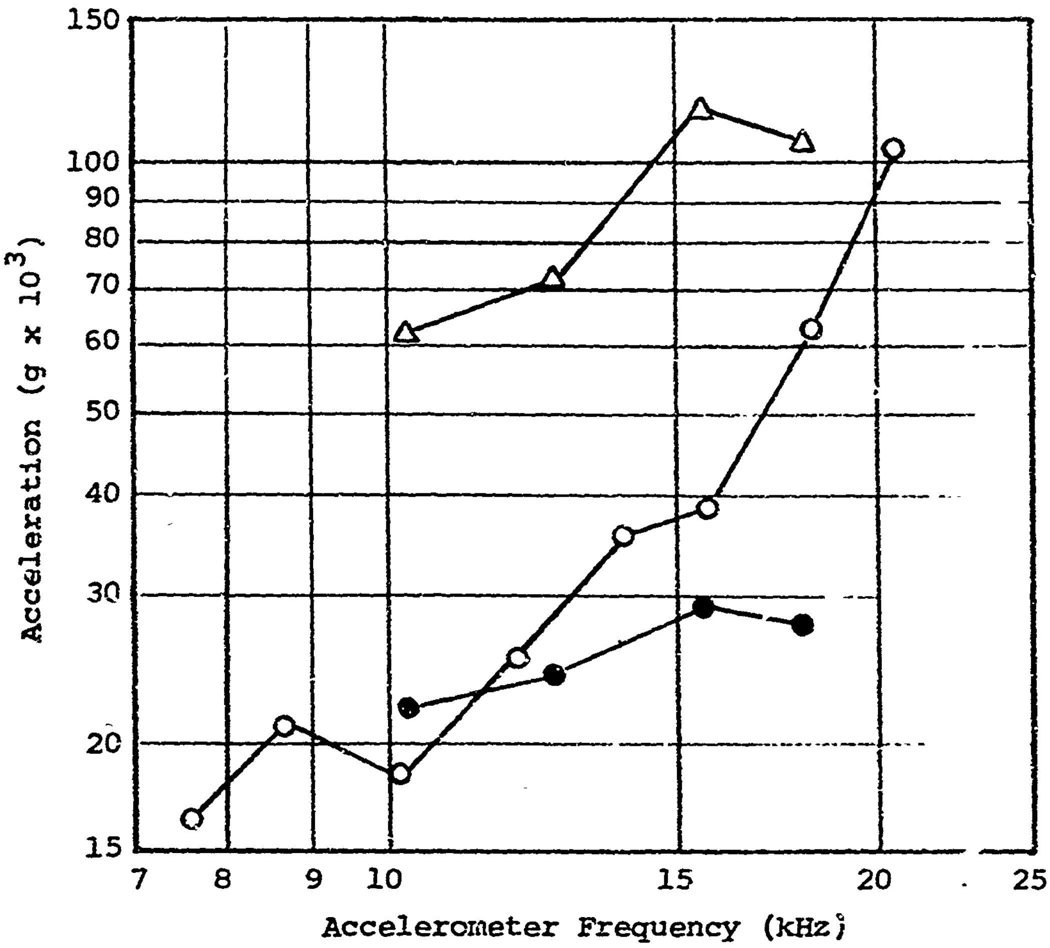
SHOCK RESPONSE TESTS

14. The WOX-5A, even the spin accelerometer, is no different in its response than the earlier model copper-ball accelerometers used to measure artillery projectile shock, reference (b), and several of the mechanical gages described in reference (c). Tests were performed, however, to check the angular response of the WOX-5A spin accelerometer and to compare 5"/54 artillery projectile shock measurements made with the WOX-5A with earlier measurements made with the Mk 4 copper-ball accelerometers.

15. The WOX-5A spin accelerometer was checked for calibration in the NOL 5-inch Air Gun using a newly developed setback-spin simulator*. To minimize error, tests were run at low acceleration where setback and spin were smooth and well within angular acceleration working range of the 5-inch gun test vehicle. Under a spin acceleration of 99,000 rad/sec^2, the accelerometer measured 89,600 rad/sec^2; under 153,000 rad/sec^2, the accelerometer measured 157,200 rad/sec^2. Two of the spin accelerometers were also fired in a 5"/54 gun (poor quality, third quarter barrel, Serial No. 16089). Spin accelerations of 494,500 and 810,000 rad/sec^2 were measured. These high values (normal spin acceleration for 5"/54 guns is about 230,000 rad/sec^2) indicate that torsional resonance or angular chatter occurred during firing (see paragraph 12).

16. One test was performed in the same 5"/54 gun (paragraph 15) with a complete prototype of the WOX-5A Accelerometer. Vertical recovery tests were performed to reduce the risk of losing the projectile; thus no ground impact data were obtained. Despite the very high landing shock, which damaged several Mk 4 Mod 0 copper-ball accelerometers used in similar tests, no damage was sustained by the WOX-5A Accelerometer. The Mk 73 VT Fuze in which the accelerometer was mounted was loose when recovered; thus it is possible the shock measurements for the round were higher than normal because of hammering. The setback measurements are plotted in figure 5 and compared

* A report on the new facility is in preparation; estimated date of publication is late 1968.



SYMBOL	TEST CONDITIONS
O———O	WOX-5A Accelerometer in Mk 73 VT Fuze fired in 5"/54, 3rd quarter, poor quality barrel. Fuze loosened during test.
●———●	Mk 4 Accelerometer* in Mk 73 VT Fuze fired in 5"/54, 4th quarter, good quality barrel.
△———△	Mk 4 Accelerometer* in WOX-1A, 5"/54 Fuze Recovery Vehicle. Loose components caused severe hammering.

*Reference (b) data

Fig. 5. Copper-Ball Accelerometer Measurements of 5"/54 Gun Shock

with measurements made in other 5"/54 gun firings, reference (b), Section 3. The transverse shocks measured are tabulated below.

Gage	Segment 1	Segment 2	Segment 3
5680 Hz	5210g	4250g	4250g
8380 Hz	5850g	7800g	9800g

ADVANTAGES AND LIMITATIONS

17. The WOX-5A capability to measure several gun shocks at once and over a wider range of frequencies is a significant improvement over earlier artillery projectile copper-ball accelerometers. Knowing more of the parameters of gun shock can make analysis of shock more meaningful and can make the job of identifying fuze problem areas easier. Even though setback shock is normally more severe than either spin or barrel slap, the latter two shocks can become severe enough to cause components to loosen and to superimpose hammering on setback shock. Thus it is important that all three shocks be measured. Also, it is important in any field test to know the severity of landing shock if damage postmortems on fuzes and other projectile components are to be meaningful. It is anticipated that the WOX-5A accelerometer will be useful in determining whether gun-fuze systems are receiving normal or excessive shock loadings.

18. Despite their simplicity, the fitting, loading and reading out of WOX-5A Accelerometers requires skilled personnel and very precise procedures. Any play, interference, or other anomalies in the accelerometer moving parts can seriously jeopardize the accuracy of gun-shock measurements. Improvements in the present design to make it more compatible for general use are contemplated.

Appendix A

WOX-5A DRAWINGS

A-1. Assembly and other drawings for the WOX-5A Accelerometer are shown in figures A-1 through A-4. The prototype drawings have not been authenticated and are included for reference only. Use of the drawings for the manufacture of the accelerometer is not recommended.

A-2. Parts considered critical to maintain equivalence between accelerometers are the discriminator shear wire and the copper ball, figure A-3. The shear wire controls the spin rate to actuate the discriminator and the copper balls control the frequency and acceleration factor of each accelerometer. All masses should be fitted (lapped or ground) to one selected diameter of balls. There should be no play between the mass and the ball and there should be less than 100 microinches of preset on the ball when the accelerometer is assembled.

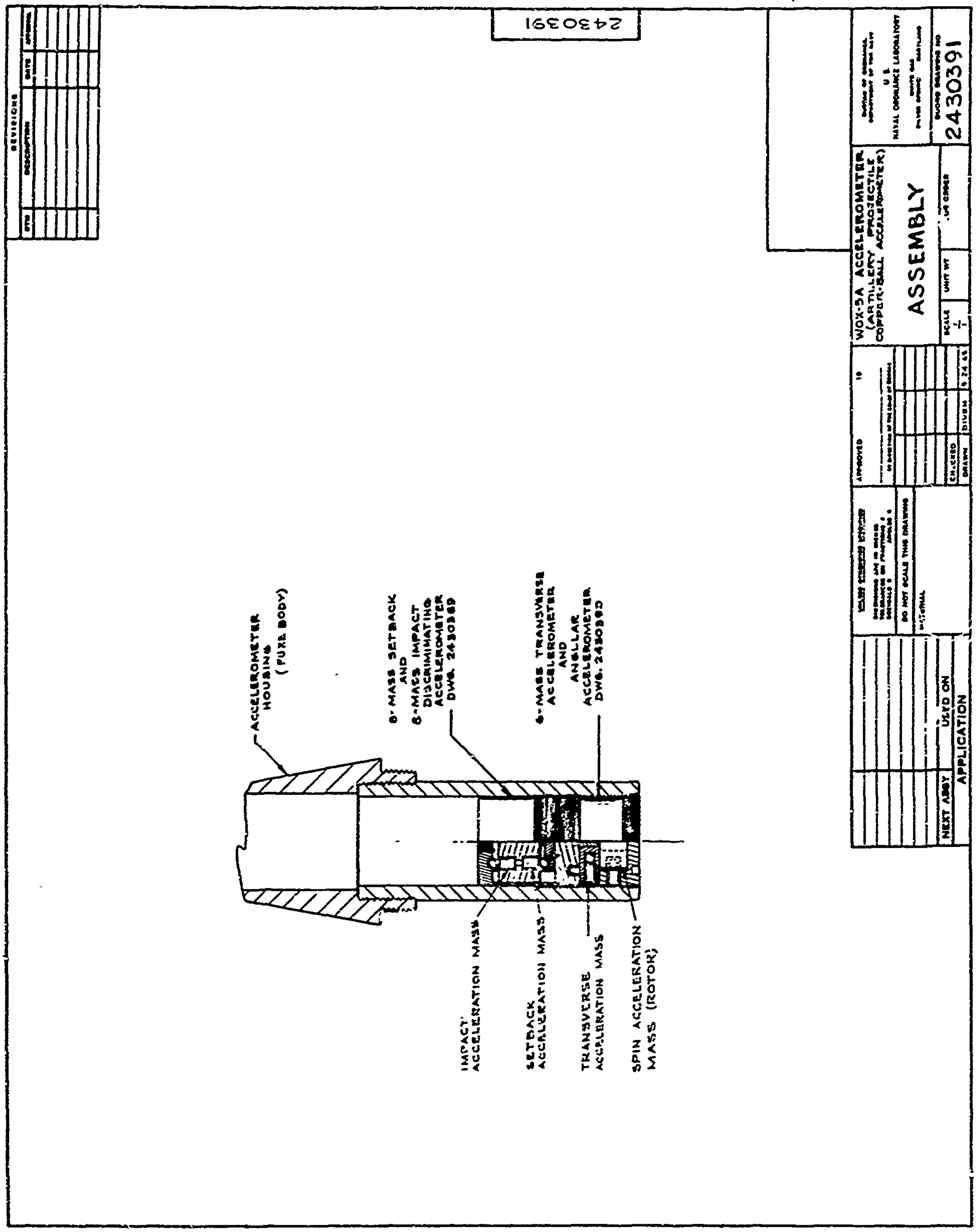


Fig. A-1. WOX-5A Accelerometer Assembly

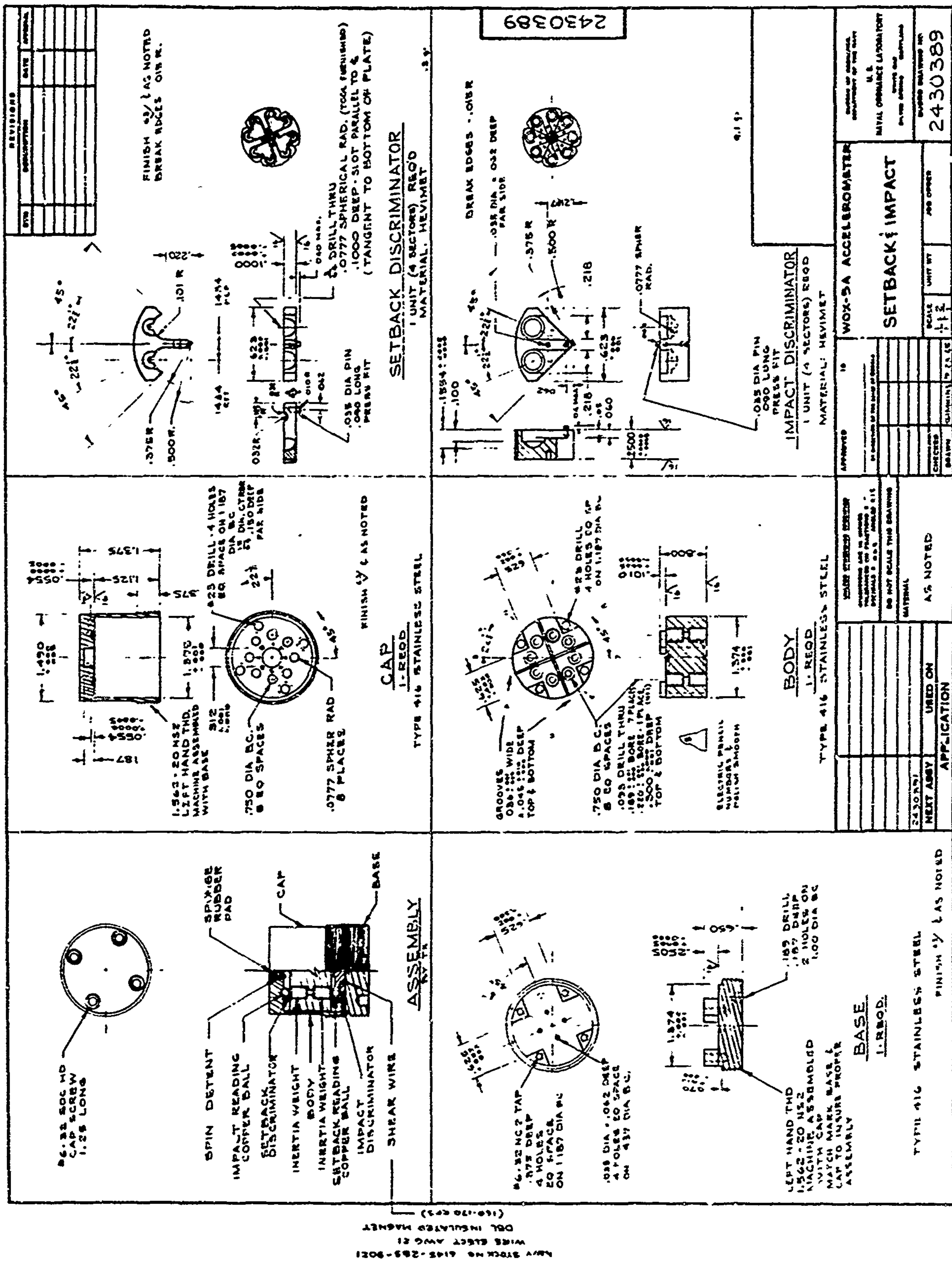


Fig. A-2. Setback and Impact Accelerometer

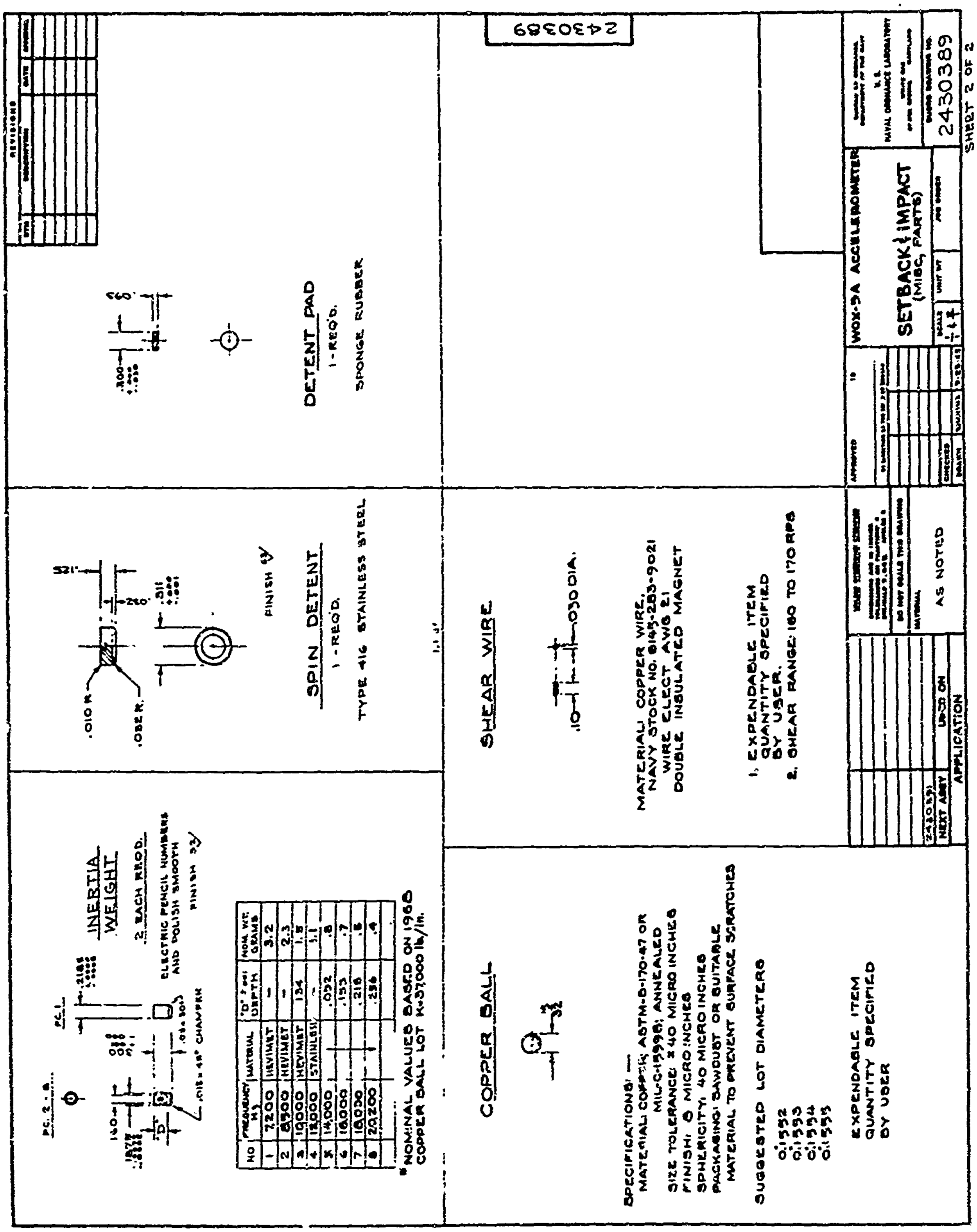


Fig. A-3. Miscellaneous Accelerometer Parts

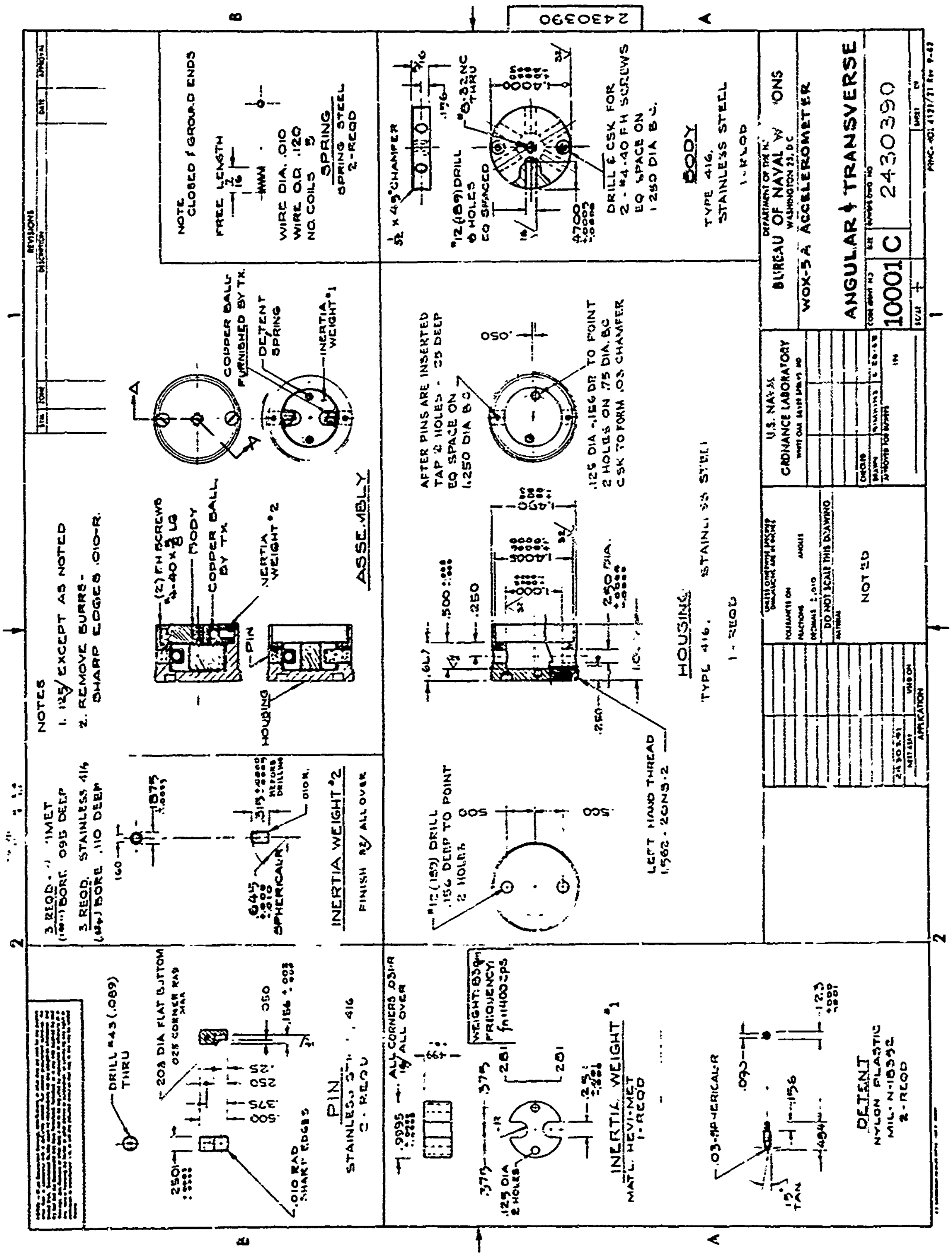


Fig. A-4. Angular and Transverse Accelerometer

Appendix B

INSTRUCTIONS IN THE USE OF THE WOX-5A ACCELEROMETER

LOADING THE ACCELEROMETER

B-1. Once a set of balls has been selected for the WOX-5A Accelerometer and the masses have been fitted to one ball diameter, say 0.1555 or 0.1552, care should be taken to use only that diameter ball. Loading the accelerometer is done as follows.

a. In the setback and impact accelerometers each ball seat is a precision, form-fitting socket as shown in figure 2B (also figure A-2 Impact Discriminator). Each socket must be thoroughly clean before the ball is inserted — even the smallest particle can cause a sizable deformation on the ball when the accelerometer is assembled. To load the accelerometer, dip each ball very lightly (one drop) in adhesive rubber (Federal Specification MMM-A-185A) and press the ball firmly in the socket with the finger or a soft object. The adhesive will flow from between the ball and socket and adhere around the waist of the ball and the edge of the socket. The adhesive prevents the ball from turning when the discriminators slide the balls from under the masses or slide from between balls and masses. Also, the adhesive holds the balls in place when the accelerometer is disassembled for measurement. When assembling the accelerometer, tighten the four bolts to a torque of 10 inch-pounds.

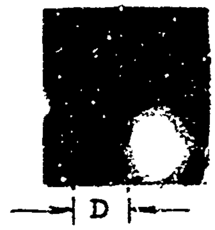
b. To load the spin accelerometer, remove the rotor and stand the housing on its side so that one pin socket is up. Dip the ball to about half its diameter in adhesive and drop it into the socket, pressing it down very lightly — the pin socket is flat at the bottom, thus there is no need to squeeze out the adhesive. Let the adhesive set for about a minute and insert the second ball if two balls are to be used. Lastly, slide the rotor in gently.

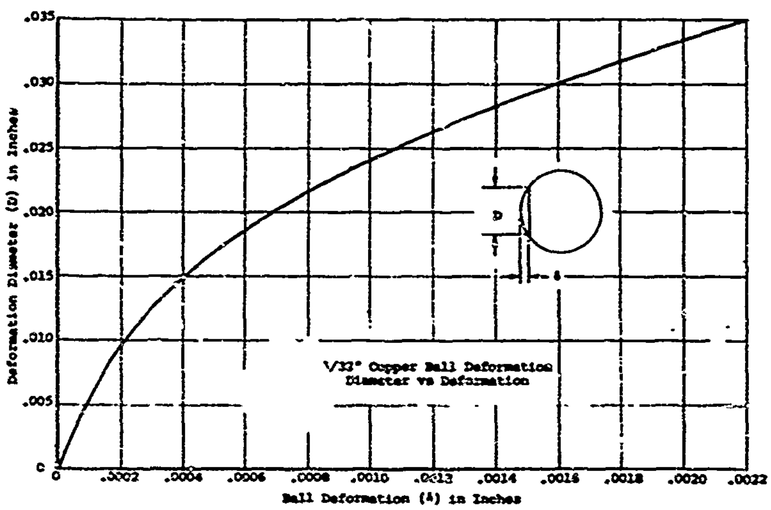
c. In the transverse accelerometer (see Assembly, figure A-4) the balls are loaded into the radial holes and the masses are inserted behind the balls with the flat side in — for practical reasons no adhesive is used. The loaded unit then is pressed into the housing and fastened in place with four screws.

B-2. Once the accelerometers are loaded, care should be taken not to drop or otherwise rough-handle them. The accelerometers should be assembled and tightened in the fuze without hammering, but with adequate torque to prevent them from becoming loose during gun firing. The recommended torque is from 20 to 25 foot-pounds.

Optical Micrometer

Micrometer
Image





Conversion Cu.~ve

Fig. B-1. Copper-Ball Measurements Using Optical Micrometer

Hammering should also be avoided when the fuze in which the accelerometers are mounted is assembled to the projectile. A strongly recommended practice in making shock measurements with mechanical gages is that those responsible for the measurements see to the entire operation from loading to reducing the data.

REDUCING ACCELEROMETER DATA

B-3. After a projectile has been fired, the accelerometers should be carefully removed from the projectile or fuze — parts should not be disassembled with impact tools or by hammering. Normally, the shocks required to additionally deform the balls in the WOX-5A Accelerometer after a shot are much higher than most rough handling shocks; however, dropping the gages, or the fuze in which they are mounted, onto steel decks or other hard objects could additionally deform the balls in the undiscriminated accelerometers.

B-4. To read out the shock data, one accelerometer at a time should be disassembled, and one ball at a time should be measured for deformation and its reading noted. The ball should then be tagged and identified to prevent mix-ups; this is important if it should be necessary to measure the ball again. Most of the balls will have relatively small deformations (less than 0".002). These balls should be measured with an optical micrometer for greater accuracy because hand micrometer measurements of small deformations are very difficult, especially for balls deformed on one side only. Figure B-1 demonstrates how the optical micrometer is used to measure ball deformation diameter when ball deformation cannot be measured directly, and how the diameter measurement is converted to ball deformation. Balls deformed over 0".002 can be measured more accurately with a hand micrometer or bench comparator.

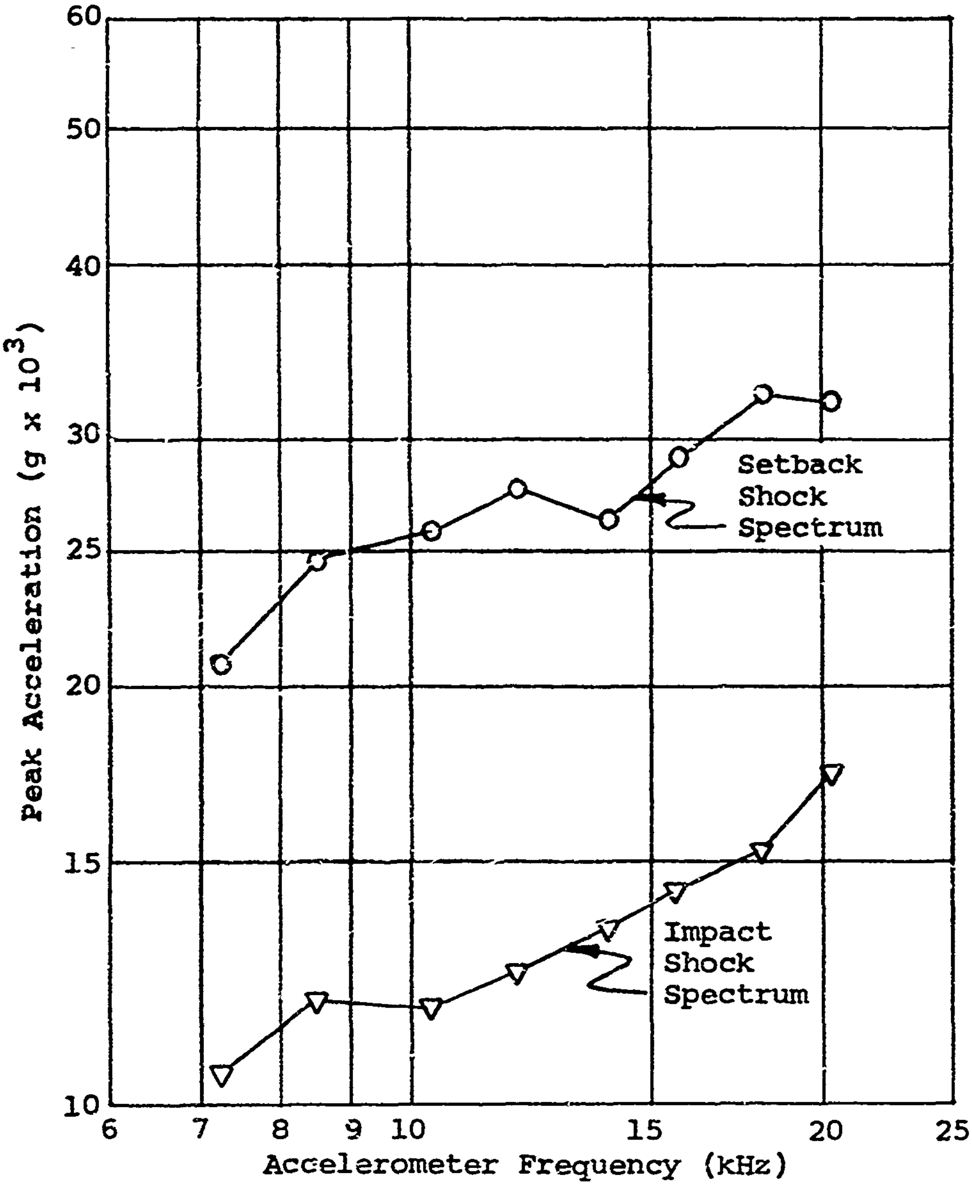
B-5. After the deformation of each ball has been measured and noted, the value is converted to acceleration by multiplying the deformation in 1/1000 of one inch by the calibration factor in Table 1. For example, if the 3.18-gram, 7200-Hz setback accelerometer reading is 0".0035, the acceleration at that frequency is

$$A = 5300 \times 3.5 = 18,550g$$

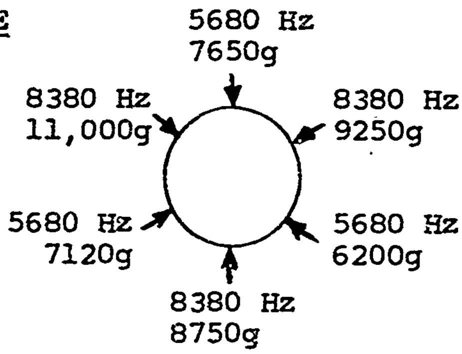
This value may be noted along with the deformation and the data in a table as shown below.

WOX-5A MEASUREMENTS OF XX-FUZE SHOCK

Accelerometer	Inertia Weight (gm)	Frequency (Hz)	Ball Deformation (0".001)	Cal. Factor (g/0".001)	Peak Acceleration (g)
Setback	3.18	7200	3.5	5300	18,500
	2.26				



TRANSVERSE SHOCK



ANGULAR ACCELERATION

(One Ball — 1026 Hz)

$\alpha = 310{,}000\ \text{rad/sec}^2$

Fig. B-2. Sample Gun Shock Data Presentation

B-6. A method frequently used at NOL to present copper-ball accelerometer data is to plot setback and impact accelerations on log-log scales as spectra, and to note the corresponding transverse and angular accelerations as shown in figure B-2.

B-7. Copper balls should not be discarded until the data are plotted and examined. It is possible to misread a ball; if this happens, the shock value will usually show up as a point far off the curve. When an apparent discrepancy shows up in the data, one or all the balls should be measured again. Another thing to look for when reducing WOX-5A data is accelerometer damage. Occasionally, landing shocks or impact of loose projectile components can be so severe that the accelerometer housings will deform and in turn deform the balls. Careful examination of any accelerometer used in artillery projectiles should be made after recovery to be sure that the readings are valid gun-shock data.

Appendix C

COMPUTATION OF SPIN ACCELEROMETER NATURAL FREQUENCY AND CALIBRATION FACTOR

Prepared by:

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C-1. The WOX-5A is the first NOL copper-ball accelerometer designed to measure angular acceleration. Therefore, the computations of the natural frequency and calibration factor are presented in this appendix. The method of determining the linear spring constant (k) of copper balls is presented in reference (c).

NOMENCLATURE

I_o = Mass moment of inertia about segment axis 0-0 (in.-lb-sec^2)

I_{cg} = Mass moment of inertia about segment centroidal axis (in.-lb-sec^2)

I_z = Mass moment of inertia about rotor centroidal axis Z-Z (in.-lb-sec^2)

W = Weight of individual rotor segment (lb)

g = 386 in. per sec^2

r = Radius of segment (in.)

ℓ_o = Distance from axis 0-0 to segment centroidal axis (in.)

ℓ_z = Distance from segment cg to rotor centroidal axis Z-Z (in.)

b = Width of segment (in.)

a = Height of segment (in.)

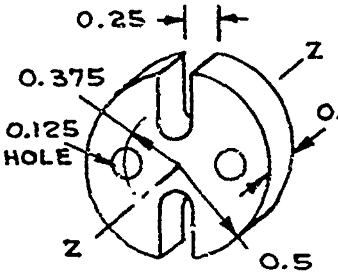
k = Linear spring constant for one copper ball (lb/in.)

T = Torque (in.-lb)

α = Angular acceleration (rad/sec^2)

f_n = Natural frequency of accelerometer (Hz)

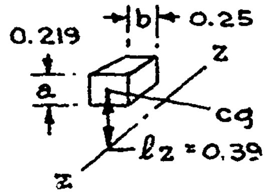
WOX-5A ANGULAR ACCELEROMETER
Mass Moment of Inertia Calculations



Rotor Details

Heavy Metal

$\rho = 0.6$ lb/cu in.



③ Outer Slot Segment

W = 0.0164 lb

$$I_{cg} = \frac{1}{12} m(a^2 + b^2)$$

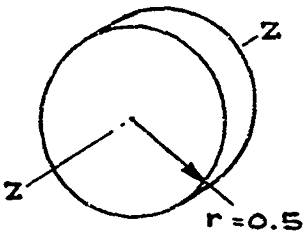
$$I_{cg} = \frac{1}{12} \times \frac{.0164}{386}\left[(.219)^2 + (.25)^2\right]$$

$$= .391 \times 10^{-6} \text{ in.-lb-sec}^2$$

$$\frac{1}{2} I_{z_3} = I_{cg} + m\ell_z^{\,2}$$

$$= .391 \times 10^{-6} + \frac{.0164}{386}(.39)^2$$

$$I_{z_3} = 13.682 \times 10^{-6} \text{ in.-lb-sec}^2$$

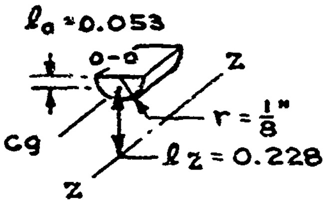


① Solid Rotor

W = 0.235 lb

$$I_{z_1} = \frac{1}{2}\frac{W}{g} r^2 = \frac{1}{2} \times \frac{.235}{386}(.5)^2$$

$$= 76.3 \times 10^{-6} \text{ in.-lb-sec}^2$$



② Inner Slot Segment

W = 0.00736 lb

$$I_o = \frac{1}{2} mr^2$$

$$= \frac{1}{2} \times \frac{.00736}{386}(.125)^2$$

$$= 0.149 \times 10^{-6} \text{ in.-lb-sec}^2$$

$$I_o = I_{cg} + m\ell_o^{\,2}$$

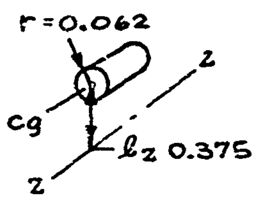
$$\frac{1}{2} I_{z_2} = I_{cg} + m\ell_z^{\,2}$$

$$\frac{1}{2} I_{z_2} = I_o + m(\ell_z^{\,2} - \ell_o^{\,2})$$

$$= .149 \times 10^{-6} + \frac{.00736}{386}\left[(.228)^2 - (.053)^2\right]$$

$$= 1.087 \times 10^{-6} \text{ in.-lb-sec}^2$$

$$I_{z_2} = 2.174 \times 10^{-6} \text{ in.-lb-sec}^2$$



④ Hole Segment

W = 0.00368 lb

$$I_{cg} = \frac{1}{2} mr^2$$

$$I_{cg} = \frac{1}{2} \times \frac{.00368}{386}(0.0625)^2$$

$$= .0186 \times 10^{-6} \text{ in.-lb-sec}^2$$

$$\frac{1}{2} I_{z_4} = I_{cg} + m\ell_z^{\,2}$$

$$= .0186 \times 10^{-6} + \frac{.00368}{386}(.375)^2$$

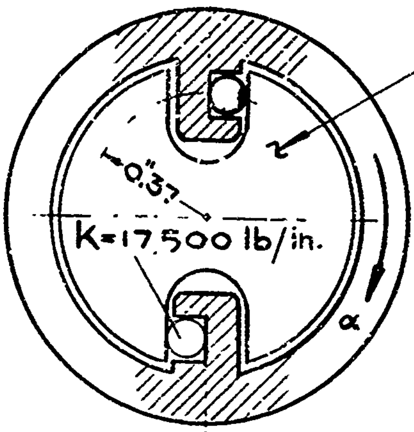
$$I_{z_4} = 2.717 \times 10^{-6} \text{ in.-lb-sec}^2$$

Composite Body

$$\sum I_z = I_{z_1} - I_{z_2} - I_{z_3} - I_{z_4}$$

$$I_z = 57.73 \times 10^{-6} \text{ in.-lb-sec}^2$$

WOX-5A ANGULAR ACCELEROMETER
Natural Frequency and Calibration Factor Calculations



TWO-BALL ACCELEROMETER

* δ = Average ball deformation in inches

$$I_z = 57.73 \times 10^{-6} \text{ in.-lb-sec}^2$$

$$f_{n_2} = \frac{1}{2\pi}\sqrt{\frac{2kr^2}{I}}$$

$$2kr^2 = 2 \times 17{,}500\ (.37)^2$$

$$= 4800$$

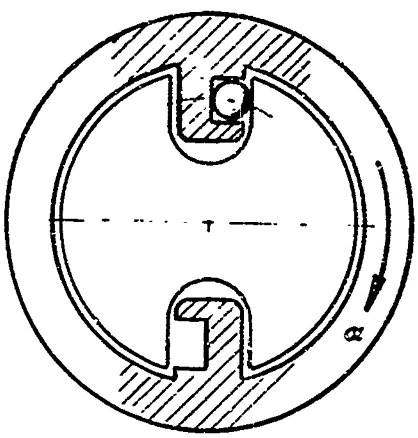
$$f_{n_2} = \frac{1}{2\pi}\sqrt{\frac{4800}{57.73} \times 10^6} = 1450 \text{ Hz}$$

$$\alpha_2 = \frac{\Sigma T}{I_z} = \frac{2k\delta{*}r}{I_z} = \frac{35000 \times .37}{57.73}\delta \times 10^6$$

$$\alpha_2 = 224.32\delta \times 10^6 \text{ rad/sec}^2$$

If δ is measured in 0".001,

$$\alpha_2 = 224{,}320 \text{ rad/sec}^2/0''.001$$



ONE-BALL ACCELEROMETER

** δ = Ball deformation in inches

I_z, k and r are the same as above

$$f_{n_1} = \frac{1}{2\pi}\sqrt{\frac{kr^2}{I_z}}$$

$$kr^2 = 17{,}500\ (.37)^2$$

$$= 2400$$

$$f_{n_1} = \frac{1}{2\pi}\sqrt{\frac{2400}{57.73} \times 10^6} = 1026 \text{ Hz}$$

$$\alpha_1 = \frac{\Sigma T}{I_z} = \frac{k\delta{**}r}{I_z} = \frac{17{,}500 \times .37}{57.73}\delta \times 10^6$$

$$\alpha_1 = 112.16\delta \times 10^6 \text{ rad/sec}^2$$

If δ is measured in 0".001,

$$\alpha_1 = 112{,}160 \text{ rad/sec}^2/0''.001$$

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13. ABSTRACT

A multipurpose accelerometer mechanically measures artillery projectile setback, spin, barrel-slap and target-impact accelerations. Twenty-three copper-ball accelerometers mount in the aft 2.75 inches of a Mk 73 VT Fuze or T-227 CVT Fuze body. Eight accelerometers measure setback at frequencies from 7200 to 20,200 Hz; eight similar accelerometers, opposite in direction, measure target impact; three pairs of accelerometers measure barrel slap (transverse acceleration) at frequencies of 5680 and 8380 Hz; one accelerometer measures spin (angular acceleration) at 1450 Hz or 1026 Hz.

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GUN BARREL SLAP MEASUREMENTS						
PROJECTILE IMPACT MEASUREMENTS						